TURBULENCE CHARACTERISTIC OF FLOW AROUND A CYLINDER

Bambang Yulistiyanto[1]

ABSTRACT

The turbulence characteristic of flow around a cylinder positioned normal to the flow in an open channel has been investigated experimentally for two types of flow. An Acoustic Doppler Velocity Profiler was used to obtain instantaneously the three directions of the velocity in the flow. Results of the experiments show the three-dimensionality of the flow expressed by the turbulence intensities, which become very important in the zone of separation behind the cylinder. From the turbulence intensities, the turbulence kinetic energy was calculated, being small at region front of the cylinder and very high at downstream region. The Reynolds-stress components are usually very small in the close vicinity of the bed.

INTRODUCTION

The vertical velocities distributions of flow around a cylinder shown a highly three-dimensional picture, being reasonably organised in the front and less organised in the back of the cylinder, where flow separation takes place (see Agui and Andreopoulos, 1992; Graf and Yulistiyanto, 1997 and 1998). The flow fields are caused by the flow separation of the turbulent boundary layer which is created in the upstream from the cylinder and rolls up to form the well-known horseshoe-vortex system (see Bolcs, 1969; Baker, 1980; Eckerle and Langston, 1987; Dargahi, 1989), which is swept around the cylinder. This type of flow occurs in a variety of situations, such as flow around bridge piers, around buildings and structures, and at different types of junctions.

This study investigates experimentally the turbulence intensities in five different planes upstream and downstream from a cylinder. Two tests have been performed, whose hydraulic characteristics are given in Table 1.

Table 1 Flow variables and channel parameters

Cylinder			Channel:uniform flow B = 2.0 [m]								
Test	D [m]	Re_D 10^5	Q [m^3/dt]	S_o 10^{-4}	n [$m^{-1/3}s$]	U_∞ [m/dt]	h_∞ [m]	B/h	U_{*cr} [m/dt]	Re_h 10^5	Fr
1	0.22	1.48	0.248	6.25	0.012	0.67	0.185	10.8	0.029	1.24	0.5
2	0.22	0.95	0.149	2.80	0.012	0.43	0.173	11.6	0.021	0.74	0.33

EXPERIMENTAL METHOD

The experiments were performed in a 43.0 [m] long and 2.0 [m] wide tilting flume. Measurements were done by using An Acoustic Doppler Velocity Profiler (ADVP) to measure the vertical profiles of the turbulence intensities. Detailed information on the experimental installation and experimental results is found elsewhere (see Yulistiyanto, 1997).

MEASURED TURBULENCE DISTRIBUTIONS

Instantaneous velocities distributions, *u(z), v(z), w(z),* were measures at different points, P(x,y,z) or P(r,α,z), in the range of $12<r[cm]<44$ and $0<\alpha[°]<180$ around the cylinder; the origin was positioned in the centre of the cylinder, P(0,0,z), whose radius is r=11 cm.

The vertical distribution of the velocities for Test 1 and Test 2 were presented elsewhere (see Graf and Yulistiyanto, 1998). They are represented in different view in Fig. 1. At the same points where the velocities distributions were measured, the turbulence intensities, $\sqrt{u'^2}$, $\sqrt{v'^2}$, $\sqrt{w'^2}$ and the Reynolds stresses, $\overline{u'w'}$, $\overline{v'w'}$ were also measured. [Note, that close to the cylinder certain components could not always be measured.] Their vertical distributions for Test 2 are shown in Figs. 2; for Test 1 they are rather similar (see Graf and Yulistiyanto, 1998).

Approaching the cylinder, the tendencies of the three components of the turbulence intensities are similar; the following can be observed:

- In the plane 0° and 45°, the profiles increase; this is very noticeable at some points near the bed.
- In the plane 90°, the profiles increase, being remarkable near the bed. The increase near the surface is the consequence of the fluctuation of the separation point. The flow in the upper layer of the water depth close to the cylinder, developes the bow-waves in the upstream edge of the cylinder, plunging in planes 45°, 90° and downstream, fluctuating the separation point at the surface in plane 90°.
- In the plane 135°, the profiles at the upper region of the water depth slightly decrease, on the other hand at the lower region they increase. At this plane, the values of the turbulence intensities are much bigger than the ones in planes 0°, 45°, or 90°. This is due to the effect of the fluctuations in the wake.
- In the plane 180°, the profiles decrease.

Approaching the cylinder one observes for the Reynolds-stress profiles, $\overline{u'w'}$, the following:

- In the plane 0° and 45°, the profiles decrease notably in the lower region, forming a concave distribution.

- In the plane 135°, the profiles at the upper region of the water depth increase whereas at the lower region decrease.
- In the plane 180°, the profiles decrease over the entire flow depth.

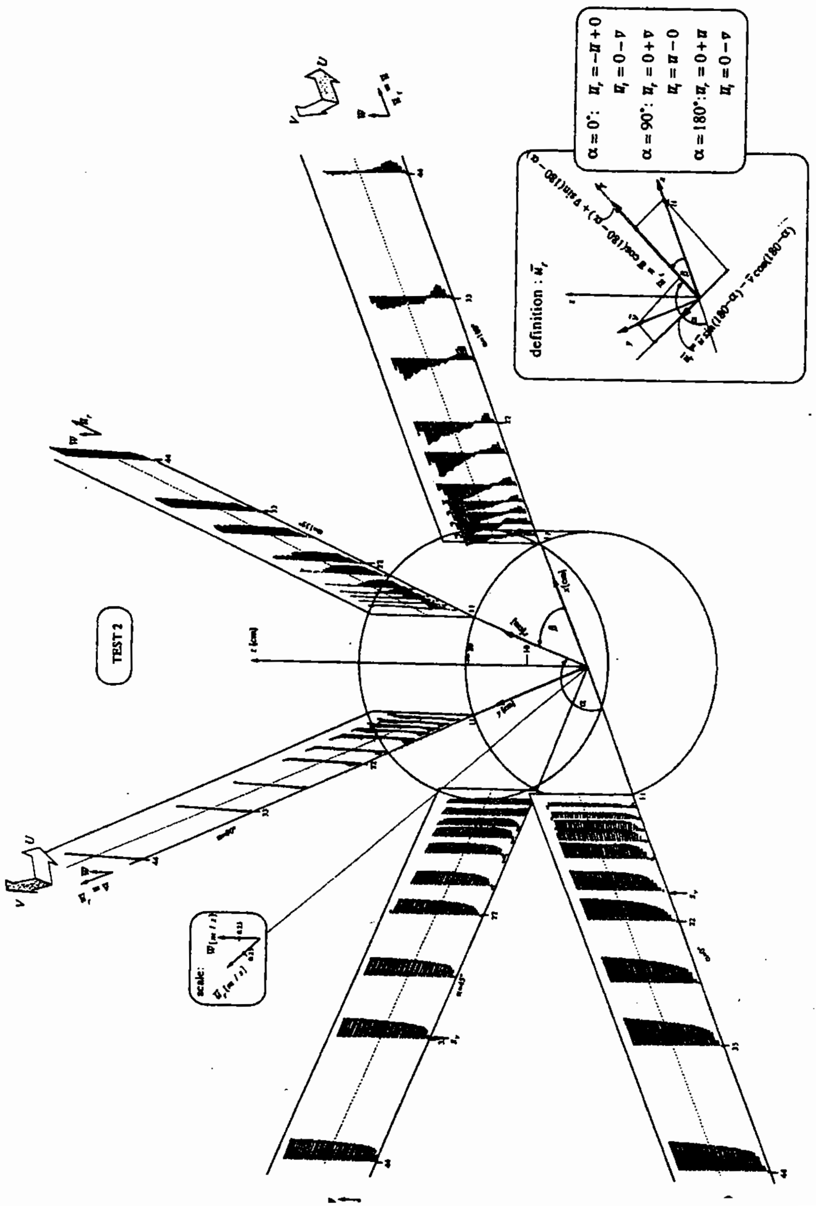
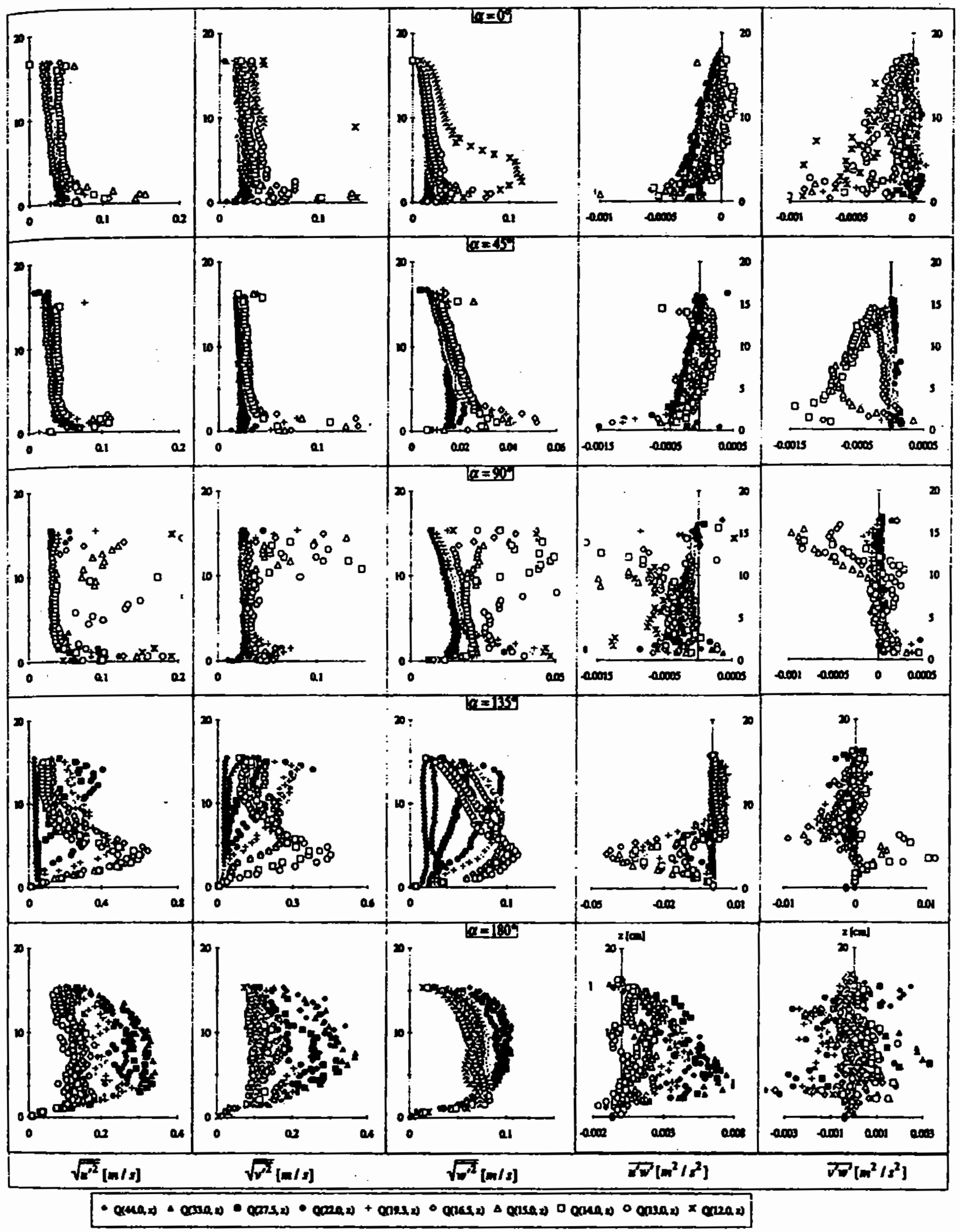


Fig. 1 Three-dimensional representation of flow in planes around the cylinder, for Test 2



Figs. 2 Distributions of the turbulence intensities and the Reynolds stresses, measured in different planes around the cylinder; for Test 2

Approaching the cylinder one observes for the other component of the Reynolds stress, $\overline{v'w'}$, the following:

- In the plane 0° and 45°, the profiles decrease, especially near the bed and at points close to the cylinder, forming triangular distribution.
- In the plane 90°, the profiles decrease, especially at the upper region.
- In the plane 135°, the profiles at the upper region of the water depth decrease, whereas at the lower region increase.
- In the plane 180°, the profiles are chaotic, showing no conclusive trend.

DISTRIBUTIONS OF THE TURBULENT KINETIC ENERGY

The turbulent kinetic energy (k) in the radial planes is calculated, using the following definition:

$$k = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2} \right)$$

The contours of the turbulent kinetic energy for each planes are presented in Figs. 3 for Test 2; Contours for Test 1 were presented elsewhere (see Graf and Yulistiyanto, 1998). Close to the cylinder there are regions where one composant of the turbulence was not measured, and are thus not shown. From these figures, one observes the maximum turbulence kinetic energy, k^{max} and its positions as the following:

Plane 0° :

Test 1: $k_{max} = 0.025$ [m²/s²] at $(r/D = 0.72 ; z/D = 0.06)$

Test 2: $k_{max} = 0.020$ [m²/s²] at $(r/D = 0.73 ; z/D = 0.04)$

Plane 45° :

Test 1: $k_{max} = 0.020$ [m²/s²] at $(r/D = 0.75 ; z/D = 0.06)$

Test 2: $k_{max} = 0.020$ [m²/s²] at $(r/D = 0.73 ; z/D = 0.06)$

Plane 90° :

Test 1: $k_{max} = 0.015$ [m²/s²] at $(r/D = 1.00 ; z/D = 0.10)$

Test 2: $k_{max} = 0.008$ [m²/s²] at $(r/D = 0.89 ; z/D = 0.04)$

Plane 135° :

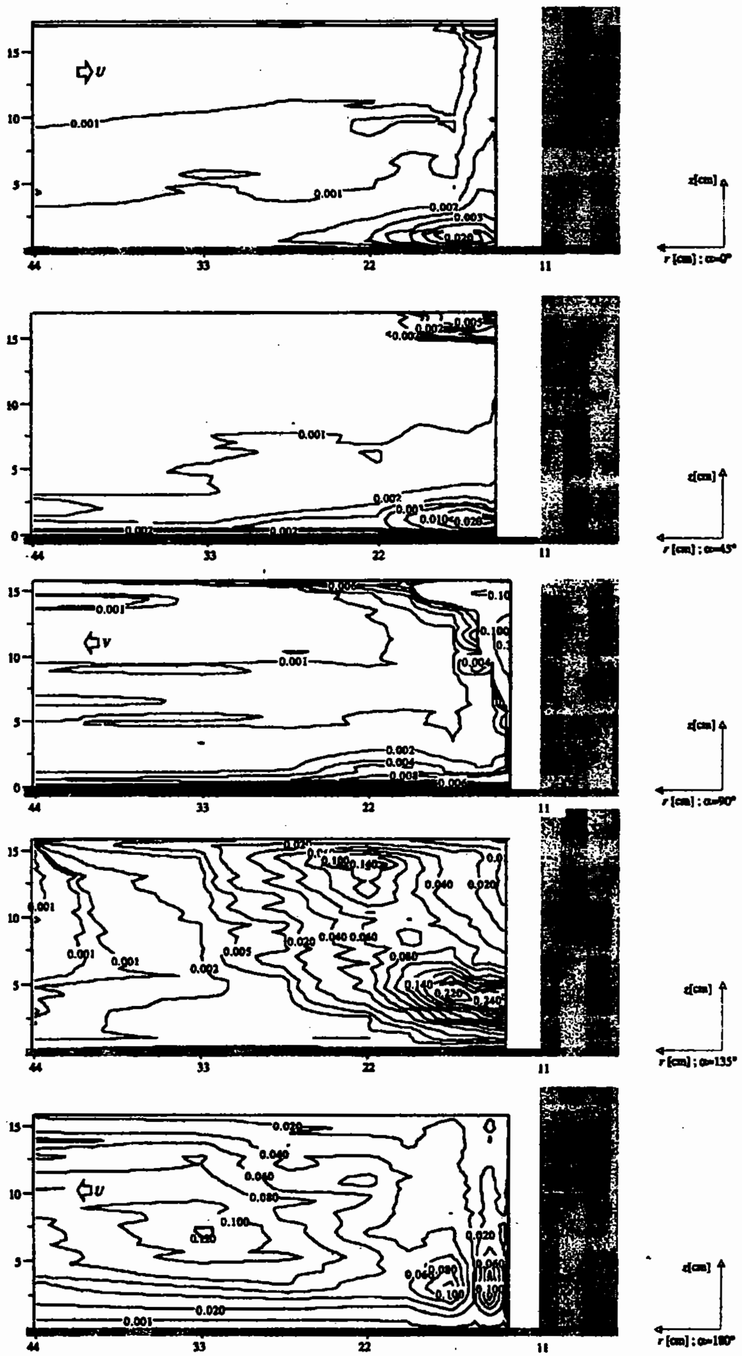
Test 1: $k_{max} = 1.200$ [m²/s²] at $(r/D = 0.75 ; z/D = 0.13)$

Test 2: $k_{max} = 0.240$ [m²/s²] at $(r/D = 0.63 ; z/D = 0.15)$

Plane 180° :

Test 1: $k_{max} = 0.400$ [m²/s²] at $(r/D = 1.47 ; z/D = 0.26)$

Test 2: $k_{max} = 0.120$ [m²/s²] at $(r/D = 1.48 ; z/D = 0.33)$



At the front of the cylinder, in planes 0°, 45°, 90°, for the both tests, the values of k_{max} are much smaller than the ones behind the cylinder.

In the planes 0° and 45°, the values of k_{max} is not much different, being equal to 0.020 - 0.025 [m^2/s^2], and its position is close each other for Test 1 and Test 2, being equal r/D = (0.72 - 0.75) and z/D = (0.04 - 0.06).

In the plane 90° the value of k_{max} is smaller than the ones in the planes 0° and 45°, and its position is farther from the cylinder.

Behind the cylinder, in the planes 157°(135°) and 180°, the values of k_{max} for Test 1 are much bigger than the ones for Test 2. However, their positions from the cylinder are not much different.

The positions of the k_{max} as well as the maximum turbulence intensity (see Yulistiyanto, 1997), are in the regions of the vortices, a small vortex in the upstream from the cylinder and a large vertical vortex in the wake of the cylinder.

The depth-averaged turbulent kinetic energy ($\bar{k}$) around the cylinder is presented in the left pictures of Figs. 4 for Test 1 and Test 2. Due to the greatly different values between the $\bar{k}$ at points in front of the cylinder and the ones in the region of the wake, the presentations are in different scale. For some points, presented with a dashed line, one component was not measured. The direction of the $\bar{k}$ is defined as the same as that of the depth-averaged velocity.

It is shown by Figs. 4 that approaching the cylinder, in planes 0°, 45°, and 90°, the $\bar{k}$ increase. The great value of one or two points in plane 90° close to the edge of the cylinder is caused by the fluctuation of the separation point at the surface.

The magnitude of the $\bar{k}$ for points in plane 157.5,° for some points in plane 135°, and for points in plane 180° are remarkable. In this region, the difference between the $\bar{k}$ for Test 1 and Test 2 is also noticeable. This shows, that the $\bar{k}$ increases at a larger flow Reynolds number.

DISTRIBUTION OF THE BOTTOM SHEAR STRESS

The bottom shear stress vector is expressed as the square of friction velocities, u_{*x}^2 and u_{*y}^2, obtained from the fitting of the Reynolds stress data near the bed. The friction velocities in planes 0°, 45° and 90° for Test 1 and Test 2 are shown in the right pictures of Figs. 4. The friction velocities at the other planes, 135° and 180°, are not presented and not discussed. The magnitude of the vectors in Figs 2 represents the values of $\sqrt{\left(u_{*x}^2\right)^2 + \left(u_{*y}^2\right)^2}$, whereas its direction is given by $arctg\left(u_{*y}^2 / u_{*x}^2\right)$.

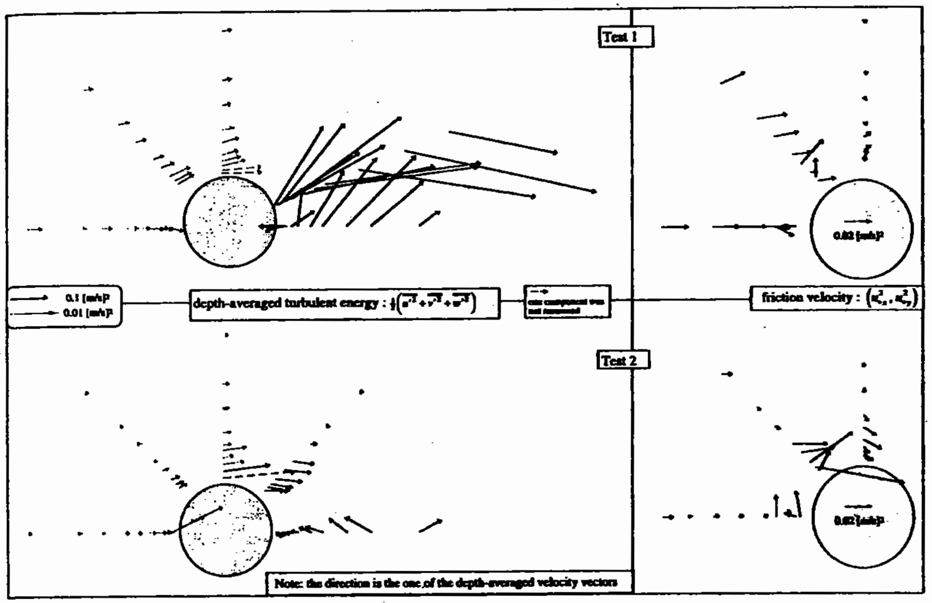


Fig. 4 Dept-averaged turbulent energyand friction velocity of the flow around the cylinder

At Figs 4, approaching the cylinder, one observes the following:

- In the plane 0°, the shear stress decreases, having the opposite direction at positions close to the cylinder. A zero value of shear stress should be at the separation point.
- In the plane 45°, for Test 2, the shear stress decreases from r = 44 to r = 33, then it increases to closer to the cylinder. The maximum value is reached at 4 to 5 [cm] from the edge of the cylinder. For Test 1, the shear stress rather decreases from r = 44 to r = 22, then it increases.
- In the plane 90°, the magnitude of the shear stress is rather constant for Test 1. For Test 2 they increase towards the cylinder.

The maximum shear stress is found in plane 45° for Test 2 at the distance about 4 to 5 [cm] from the edge of the cylinder. This implies that for a mobile bed, the beginning of the scour will be in this region. It is noted that in front of the cylinder, in the separation region, the existence of the flow reversal very close to the bed gives the negative shear stress.

SUMMARY

dimensional flow has been documented with the turbulence fields, showing the following important findings:

- In front of the cylinder near the bed, where the horseshoe-vortex system establish, the turbulence gets to be very strong, produces a high bed shear stress beneath it.
- The maximum shear stress is found in plane 45°. This implies that for a mobile bed, the beginning of the scour will be in this region.
- At region front of the cylinder, the values of k^{max} are much smaller than the ones behind the cylinder.
- The positions of the maximum turbulent kinetic energy, k^{max} as well as the maximum turbulence intensity, are in the regions of the vortices, a small vortex in the upstream from the cylinder and a large vertical vortex in the wake of the cylinder

REFERENCES

Agui J.H. and Andreopoulos J., 1992, "Experimental investigation of a three-dimensional boundary layer flow in the vicinity of an uprigth wall mounted cylinder", *J. Fluids Engineering*, Vol. 114, pp. 566-576.

Baker C.J., 1980, "The turbulent horseshoe vortex", *J. Wind Engineering and Industrial Aerodynamics*, Vol. 6, pp. 9-23.

Bolcs A., 1969," Strömungsuntersuchungen im Wassergerinne bei Unterschall- und Überschallgeschwindigkeiten ", *Escher Wyss Mitteilungen*, 42, Heft 1.

Dargahi B., 1989," The turbulent flow fields around a circular cylinder", *Experiments in Fluids*, Vol. 8, pp. 1-12.

Eckerle and Langston, 1987," Horseshoe vortex formation around a cylinder", *ASME J. of Turbomachinery*, Vol. 109, Apr. pp. 278-285.

Graf W.H. and B. Yulistiyanto, 1997, "Experiments on Flow upstream of a Cylinder", PROC., XXVII Congr., Int. Assoc. Hydr. Res., Vol. 1, San Francisco, USA.

Graf W.H. and B. Yulistiyanto, 1998, "Experiments on Flow around a cylinder; the velocity and vorticity fields", *J. Hydraulic Research*, Vol. 36, pp. 637-653.

Yulistiyanto B., 1997, *Flow around a cylinder installed in a fixed-bed open channel*, PhD dissertation 1631, Ecole Polytechnique federale, Lausanne, CH.